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SEA-ICE AND SURFACE WATER CIRCULATION, ALASKAN CONTINENTAL SHELF

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16. Abstract

The objectives of this study are to delineate the general surface water circulation, estimates of sediment flux, pathways of sediment transport, and formation of sea ice and its movement in relation to sea mammal distribution on Alaskan Shelf.

During the reporting period water parameters from the test areas and other parts of the Alaskan shelf were measured. The measured parameters were correlated to the ERTS-1 imagery in an effort to develop methods to use ERTS-1 imagery from the entire shelf. The results so far suggest that ERTS-1 imagery is capable of identifying turbid runoff which can be used as a tracer to understand the surface circulation and mixing of water masses on the shelf.

Utility of ERTS-1 imagery for mapping of various types of sea ice and their movement has been highly successful. Routine plotting of sea ice movement over a period of several seasons may result in improved navigation and the understanding of dynamics of sea ice formation and its extension in the Bering Sea.

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I. INTRODUCTION

This report summarizes the work performed and conclusions reached during the second six months Contract No. NAS5-21833, ERTS-1 project no. 110-8, "Sea-Surface Circulation, Sediment Transport, and Marine Mammal Distribution, Alaska Continental Shelf." The purpose of this project has been to trace water, sediment, and ice movements, and observe the factors controlling sea mammal distribution from ERTS multi-spectral scanner imagery.

The program for obtaining ground truth synchronous to the ERTS over-head passes was initiated in Cook Inlet when two attempts (22-25 August 1972 and September 1972) were made. On both occasions extensive cloud cover did not permit ERTS-1 to obtain useful imagery from this area. Excellent ERTS-1 imagery was obtained for Cook Inlet on 4 and 5 November 1972. The analyses of ground truth data and the ERTS-1 imagery obtained from Cook Inlet demonstrated that general water circulation patterns can be delineated from ERTS-1 imagery and various bands are useful for identifying water masses with suspended load varying from 1 mg/l to 2,000 mg/l. The bulk of the turbid waters introduced from the Knik and Matanuska rivers in Knik Arm and relatively clear oceanic waters entering near the mouth of Cook Inlet served as a tracer to delineate the circulation in this estuary.

The analyses of ERTS-1 imagery (ID 1039-21371 and 1054-21203) from Bristol Bay region similarly confirmed that sediment plumes and turbid waters are excellent finger prints for tracing sediment source and sediment pathway on Alaskan shelf. The configuration of sediment plume was indicative of the surface water circulation and confirmed a counterclockwise gyre in Bristol Bay proposed by Sharma *et al.* (1972).

II. STATUS OF PROJECT

A. Objectives

The overall objectives of this study are to delineate the general surface water circulation, estimates of sediment flux, pathways of sediment transport, and formation of sea ice and its movement in relation to sea mammal distribution on Alaskan Shelf. The study includes observations of geographical distribution of fresh water input and silt-laden coastal waters of Alaska. After a positive correlation between radiance values (reflectance spectrum) on ERTS-1 imagery and ground truth is accomplished, estimates of amounts of sediments carried offshore annually will be made. The general movements of waters on the shelf will be delineated using ERTS-1 imagery and the VP-8 density slicing equipment utilizing suspended load as a tracer. Once the entire shelf is adequately covered by ERTS-1 imagery an atlas showing surface sediment distribution, general water circulation and ice cover will be compiled. This atlas will provide the baseline data for pristine Alaskan coastal environment and will serve as a useful guide for future resource development in Alaska. Besides determining the distribution of sediments it now appears that it should be possible to locate regions of high productivity in Bering Sea with the use of ERTS-1 imagery. Preliminary studies indicate that certain areas of high productivity produces a distinct coloration in the surface sea waters which should be discernible on various bands of ERTS-1 imagery.

Large scale survey of suspended load distribution in surface waters of Alaskan shelf was initiated in February 1973. Bering Shelf region has been continually sampled from June-August 1973. Central Gulf of Alaska including Prince William Sound was sampled during February 1973 and May 1973. The southern Aleutian Shelf between Seward and Dutch Harbor was sampled during July and August 1973. Most cruises were scheduled to obtained ground truth data synchronous to overhead satellite pass. The data obtained will not only establish the correlation between the suspended sediment load in sea water and the radiance values but also the effects of salinity temperature, and seasonal productivity of sea water on variance of reflectance spectrum of different bands of ERTS-1 imagery.

B. <u>Accomplishment during the reporting period</u>

(a) Central Gulf of Alaska

The water parameters measured in Central Gulf of Alaska during February 21-24, 1973 were correlated with ERTS-1 imagery ID 108-20284. A striking similarity between the suspended sediment distribution in this region and the distribution of turbid waters displayed in ERTS-1 imagery was observed although the imagery was obtained in October 1972. Sediments introduced in the Gulf of Alaska by the Copper River are carried westward along the shore as a distinct plume. Part of the plume is drawn into Prince William Sound where it disperses. Incoming relatively clear oceanic waters moves northeast between Middleton Island and Kayak Island (Figs. 1, 2 and 3) and carries the plume originating from Bering Glacier northwards. Slightly turbid waters observed offshore is result of Ekman transport of surface waters. A distinct anticlockwise surface water circulation is prevalent in this region.

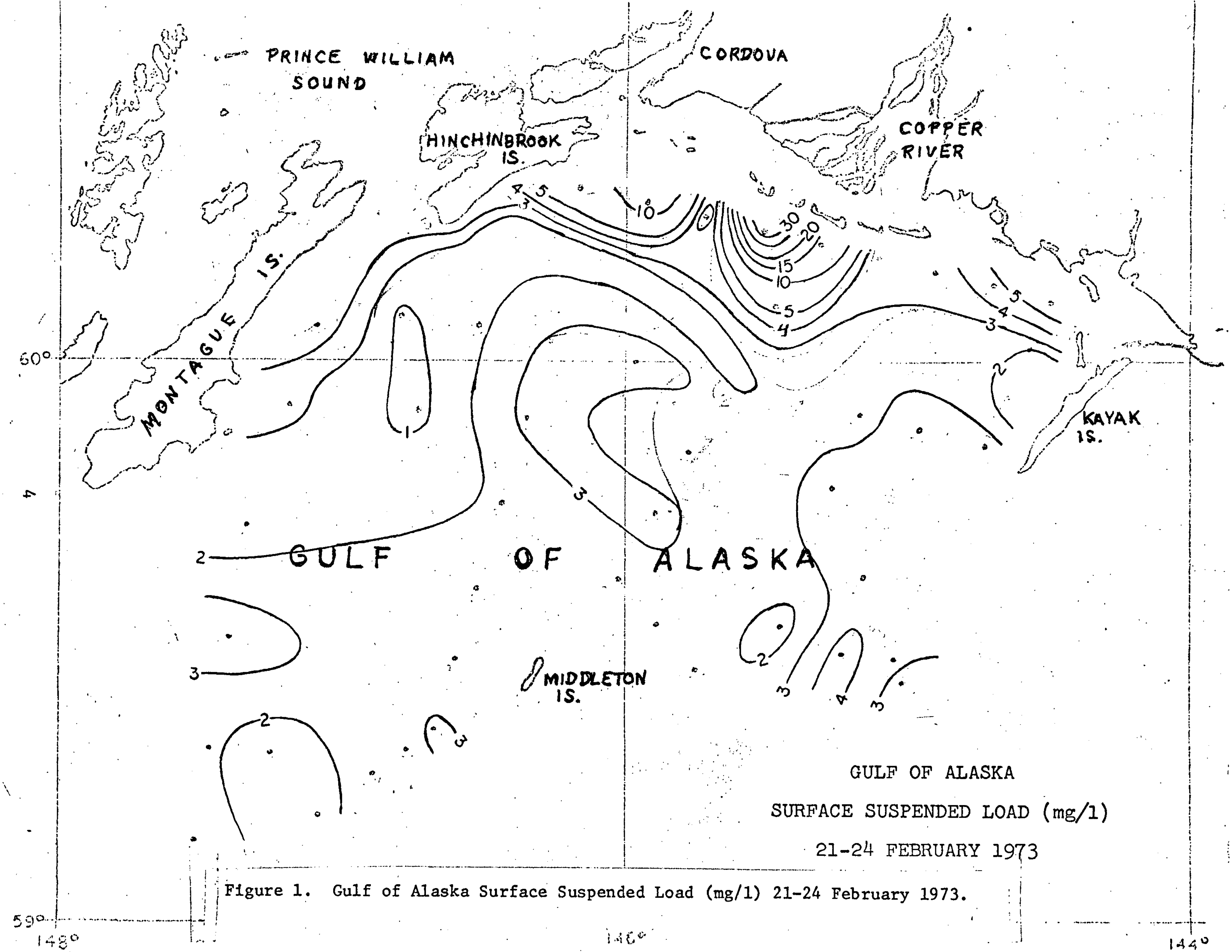

Figure 1. Gulf of Alaska Surface Suspended Load (mg/l) 21-24 February 1973.

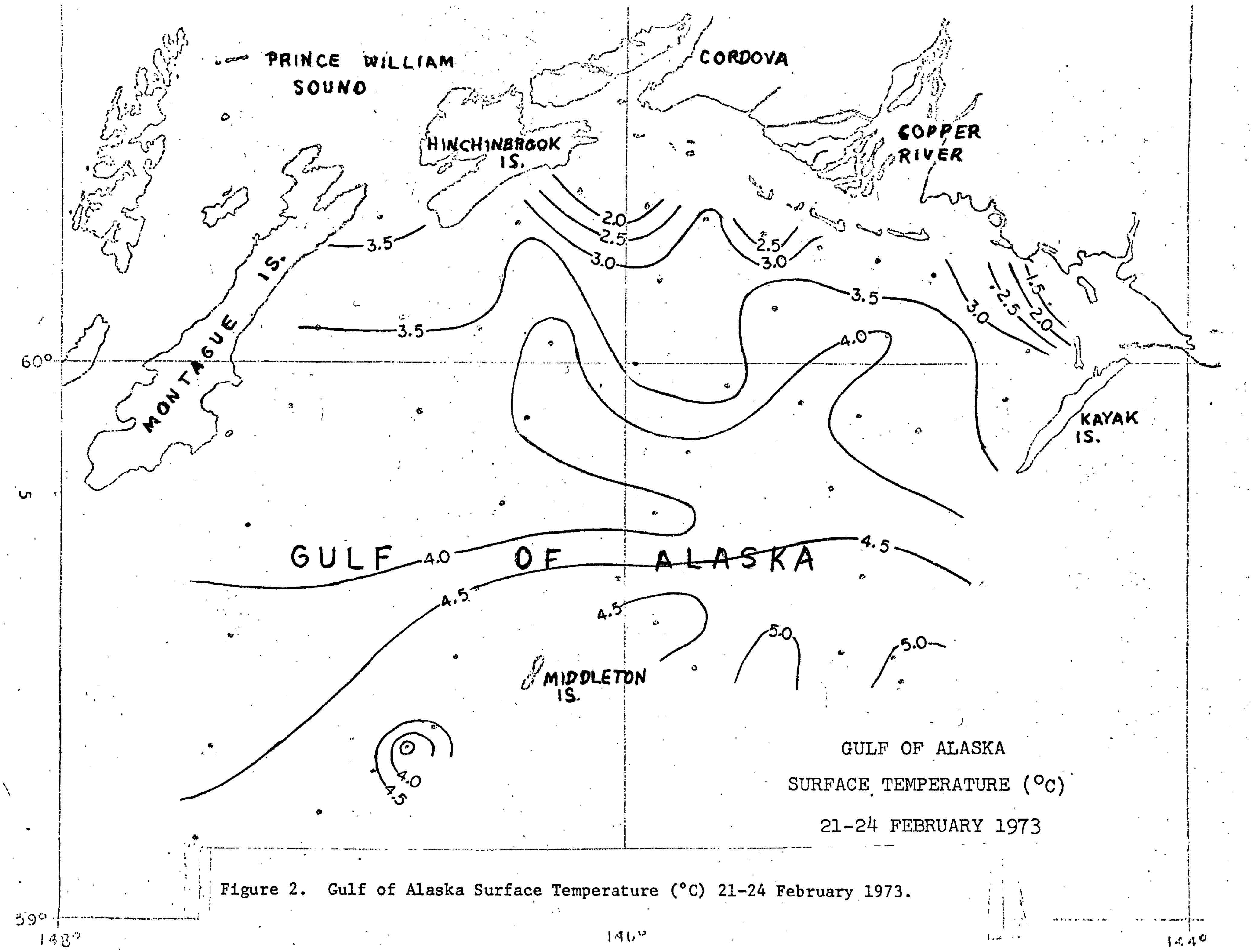

Figure 2. Gulf of Alaska Surface Temperature (°C) 21-24 February 1973.

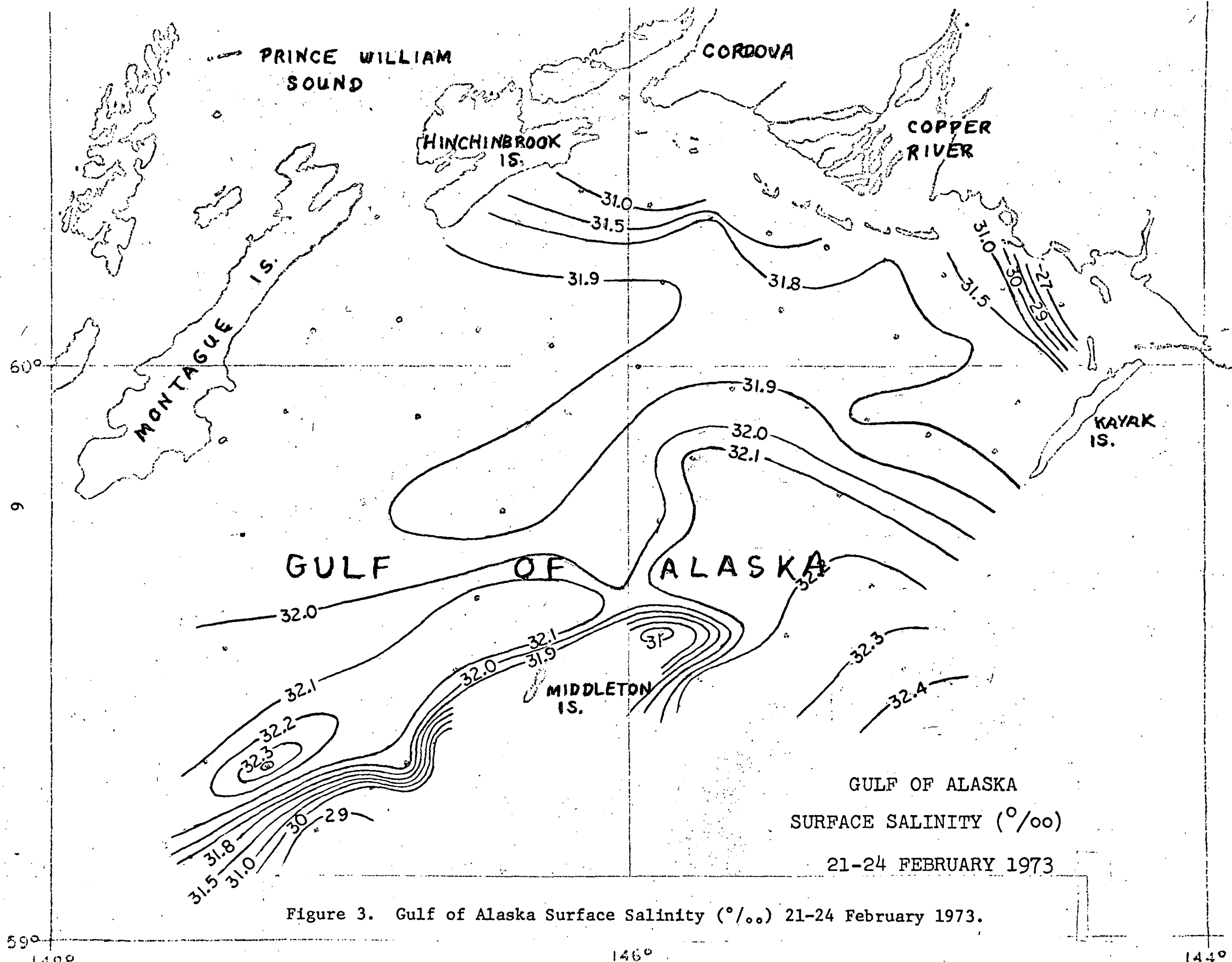

Figure 3. Gulf of Alaska Surface Salinity (°/₀₀) 21-24 February 1973.

(b) Cook Inlet

Three cruises were conducted in Cook Inlet to measure suspended sediment load and temperature. Salinity measurements were included during one of the cruises. These cruises were scheduled (27 March 1973, 14 April 1973, and 7-8 June 1973) to obtain ground truth data during the overhead ERTS-1 satellite passes. The stations for sampling were arranged to cover an area with maximum variation in suspended sediment in minimum time. Cloudy skies during the first cruise did not permit ERTS-1 to obtain imagery of the area. April 14, 1973 was also cloudy, but during the subsequent pass ERTS-1 did obtain good imagery and we hope to use the imagery obtained on April 15, 1973 for ground truth correlation. The last cruise during June was conducted under partly cloudy skies. The preliminary examination of the imagery revealed that the area of sample collection was indeed cloud free and the imagery may be quite useful for ground truth correlation.

So far five oceanographic cruises have been conducted in Cook Inlet. The data obtained from first two cruises have been reported earlier. The results of last three cruises are shown in Figures 4, 5, 6, 7, 8, 9, 10 and 11. The measurements of water parameters during these cruises confirms the anticlockwise water circulation in Cook Inlet proposed earlier. Interestingly the results of 14 April 1973 cruise suggest slight lateral shifting of turbid and incoming oceanic water during each tidal cycle.

The hydrographic data obtained from Cook Inlet almost covers the entire summer fresh water runoff season. The overall water circulation pattern emerging from the analyses of the data from each cruise appears

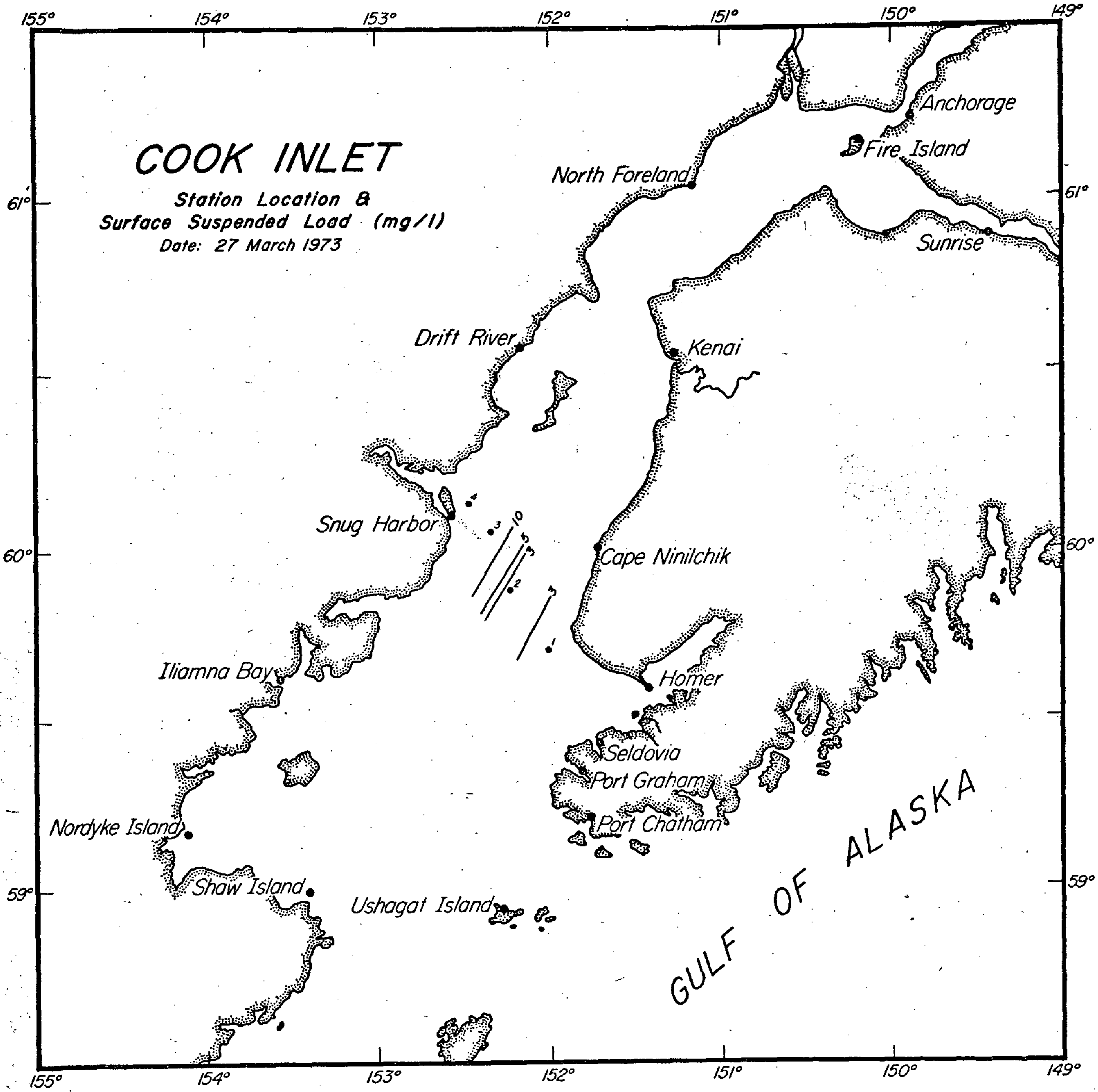

Figure 4. Suspended load distribution (mg/l) in surface waters of Cook Inlet, Alaska; on 27 March 1973.

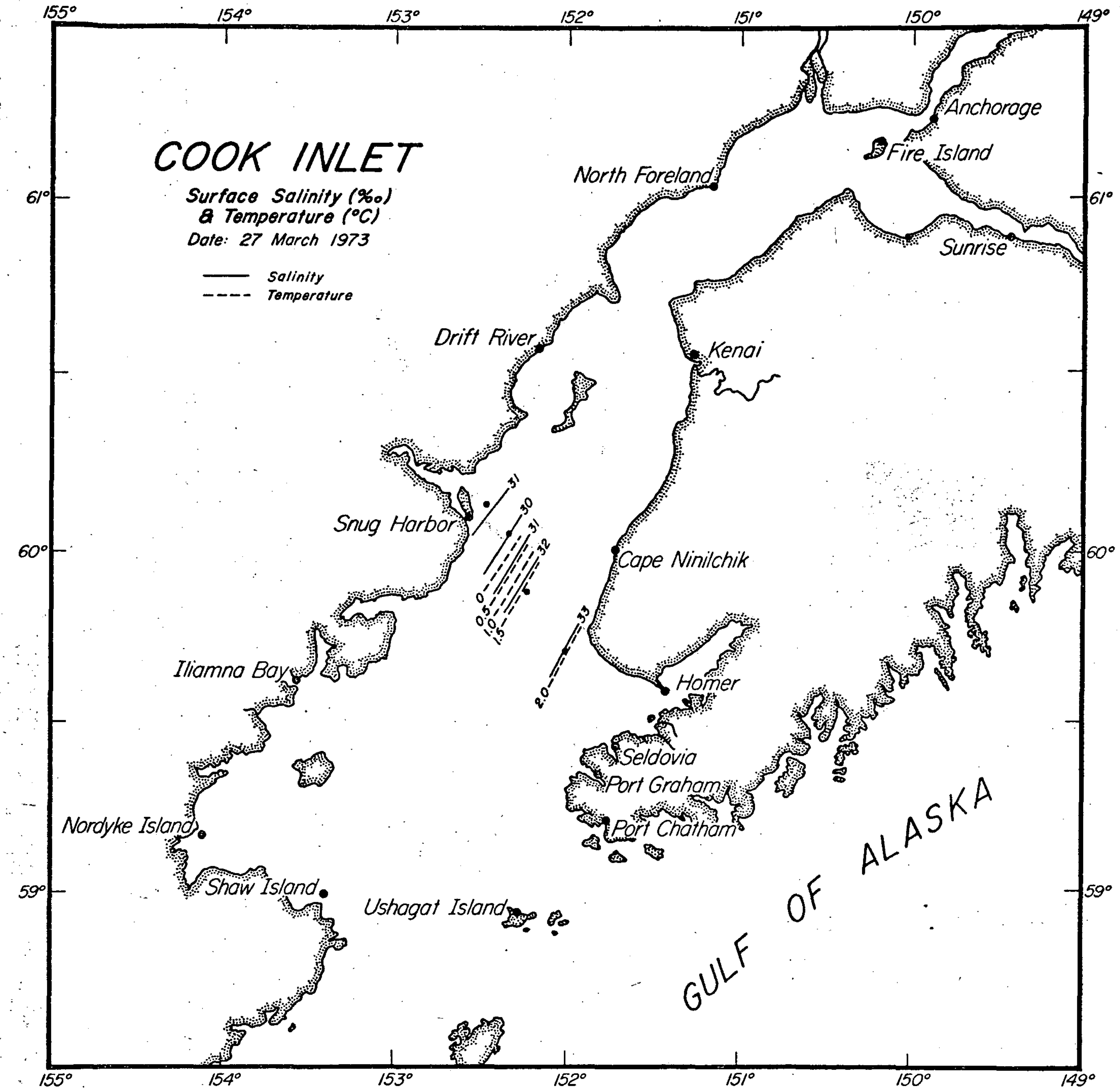

Figure 5. Surface water isohalines (°/°°) and isotherms (°C) in Cook Inlet, Alaska; on 27 March 1973.

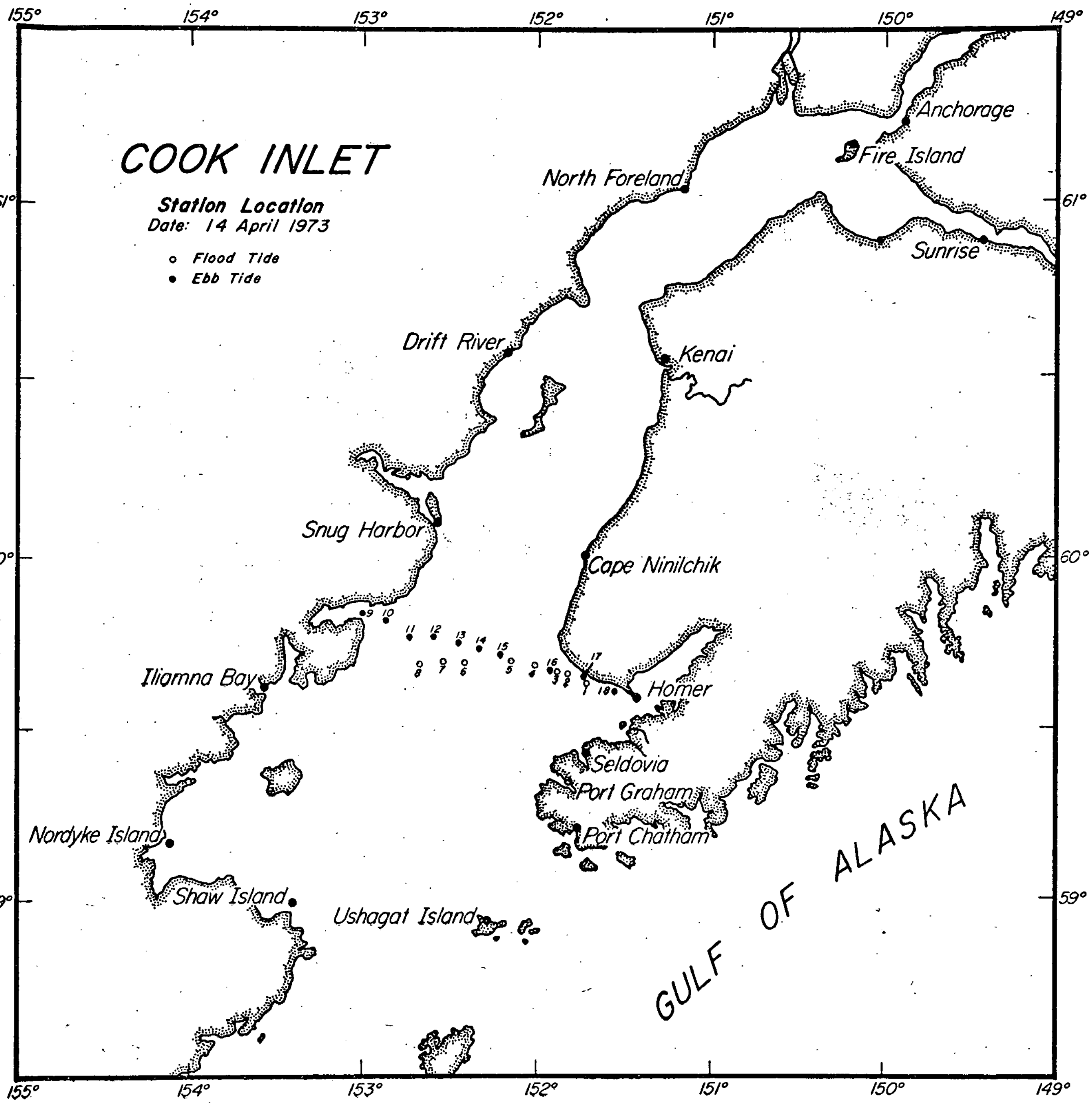

Figure 6. Station locations for sampling in Cook Inlet, Alaska; 14 April 1973.

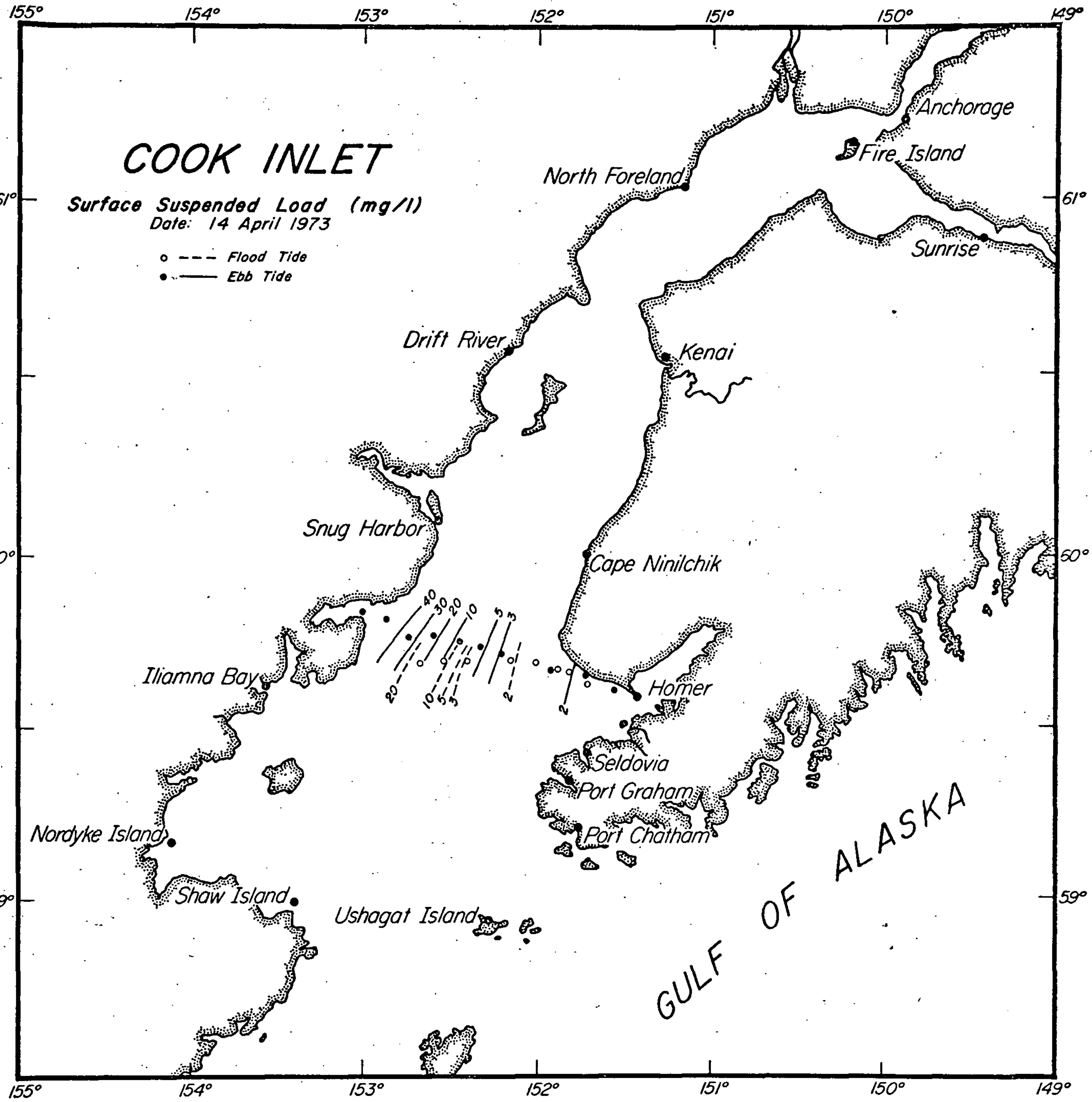

Figure 7. Suspended load distribution (mg/l) in surface waters of Cook Inlet, Alaska; on 14 April 1973.

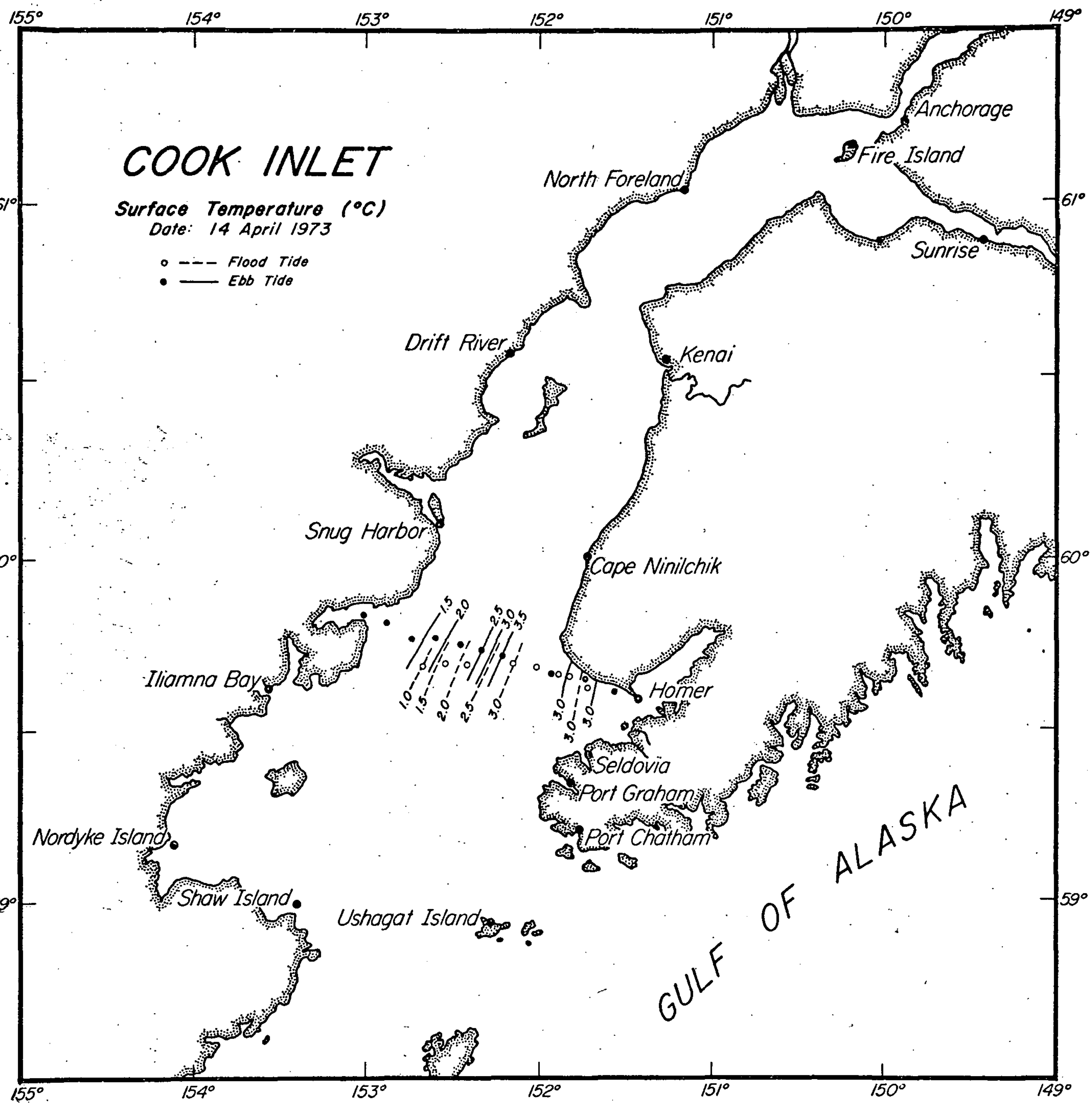

Figure 8. Surface water isotherms (°C) in Cook Inlet, Alaska; on 14 April 1973.

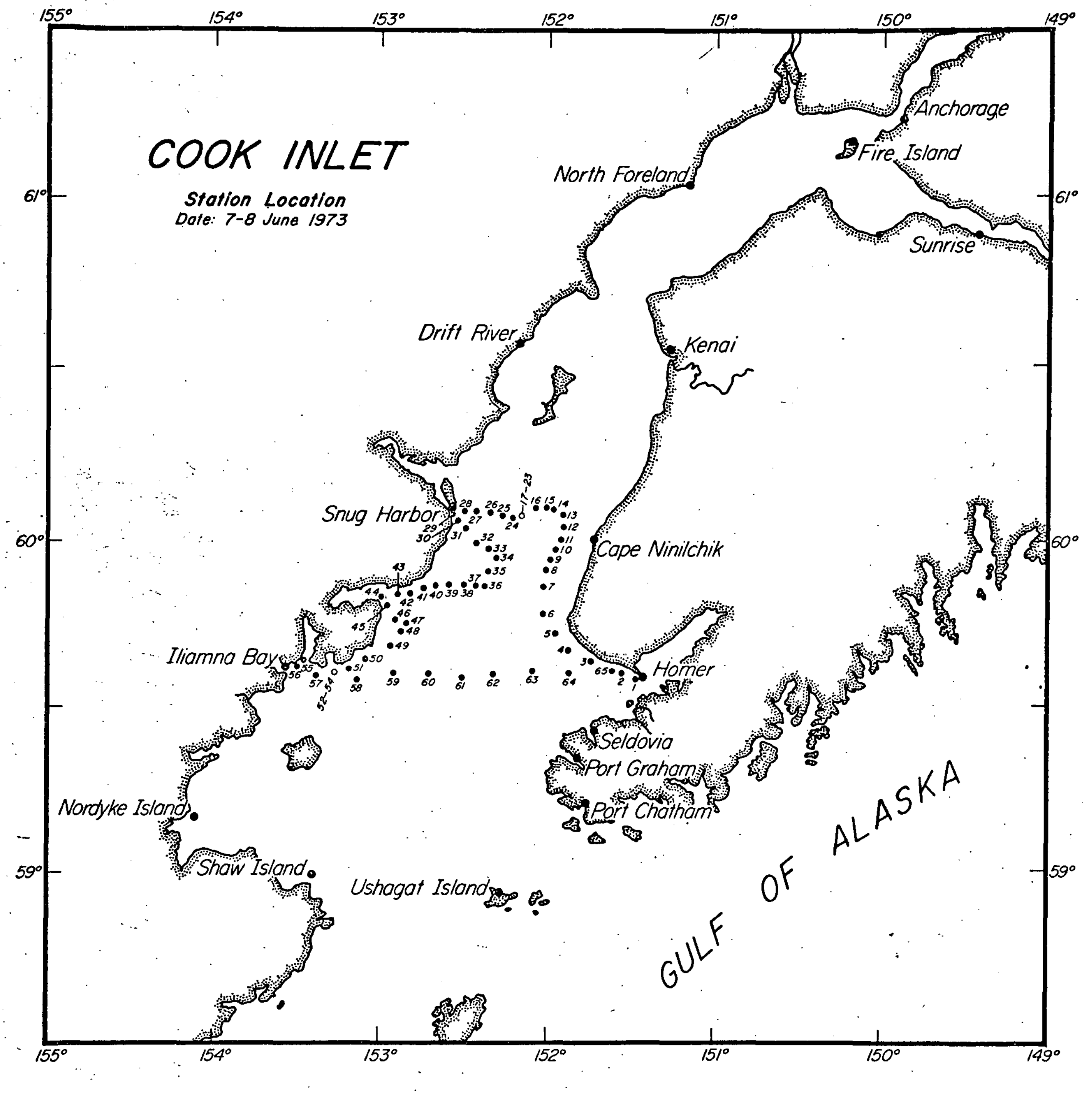

Figure 9. Station locations for sampling in Cook Inlet, Alaska; 7-8 June 1973.

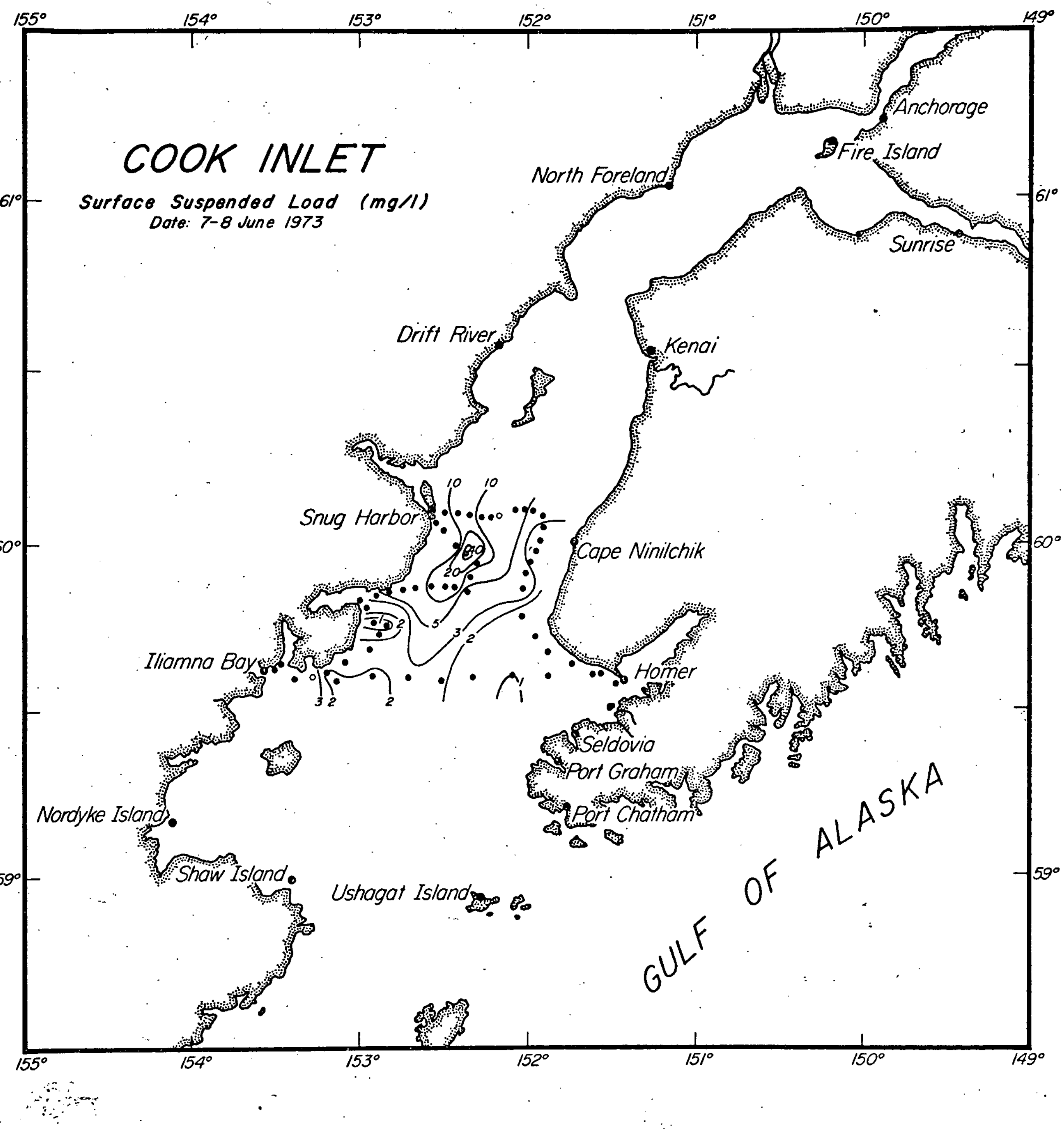

Figure 10. Suspended load distribution (mg/l) in surface waters of Cook Inlet, Alaska; during 7-8 June 1973.

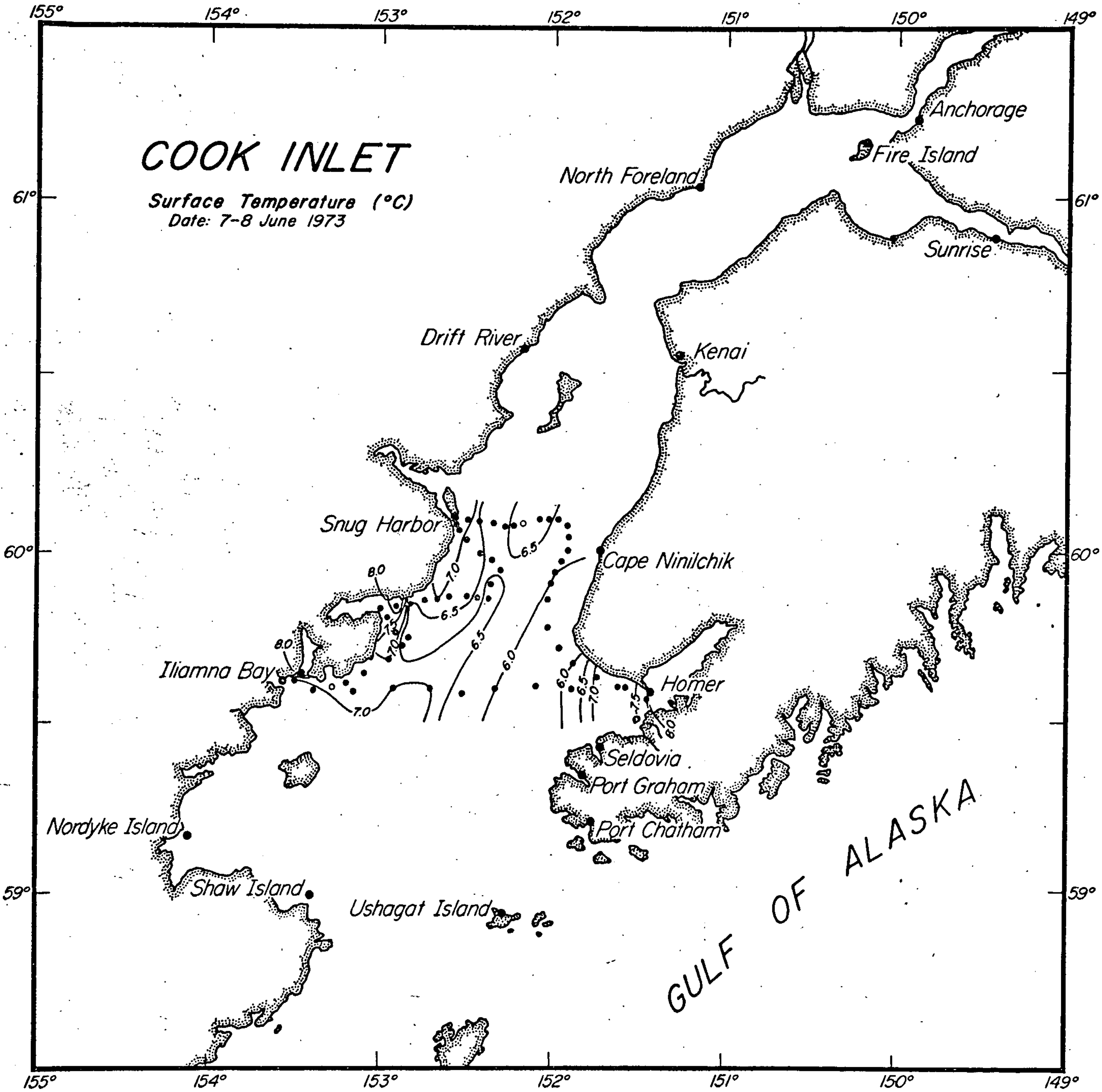

Figure 11. Surface water isotherms (°C) in Cook Inlet, Alaska; during 7-8 June 1973.

to be consistent throughout the season. Salinity, temperature and sediment concentration in suspension in upper Cook Inlet change with season and also with fresh water discharge, however, these parameters remain relatively unchanged near the mouth of Cook Inlet. Fortunately this water mass will provide us the standard for the density slicing of the entire Cook Inlet imagery using VP-8 equipment. The preliminary investigation based on density slicing show distinctly various bands of suspended sediment concentrations in regions which appeared uniformly gray on dodged print images. Using sediments concentrations as tracer we hope to delineate circulation pattern, influx of fresh water mass and mixing in upper Cook Inlet. The generalized water circulation and suspended sediment distribution in Cook Inlet is shown in Figure 12.

(c) Bering Sea

An extensive and thorough survey of suspended sediment distribution in central and eastern Bering Sea was initiated during June, July and August 1973. At the completion of the sampling period over 2,000 water samples will be collected and various parameters measured. The offshore waters in Bering Sea contain low concentrations of suspended load. In regions of high productivity the material in suspension is mostly biogeneous. In order to obtain variations in suspended loads accurately an elaborate and precise method for weighing filter papers was developed.

The past studies for the measurements of suspended load have demonstrated the need for a routine procedure for the preparation and weighing of filter papers. Differences in humidity during weighing of filter paper may cause

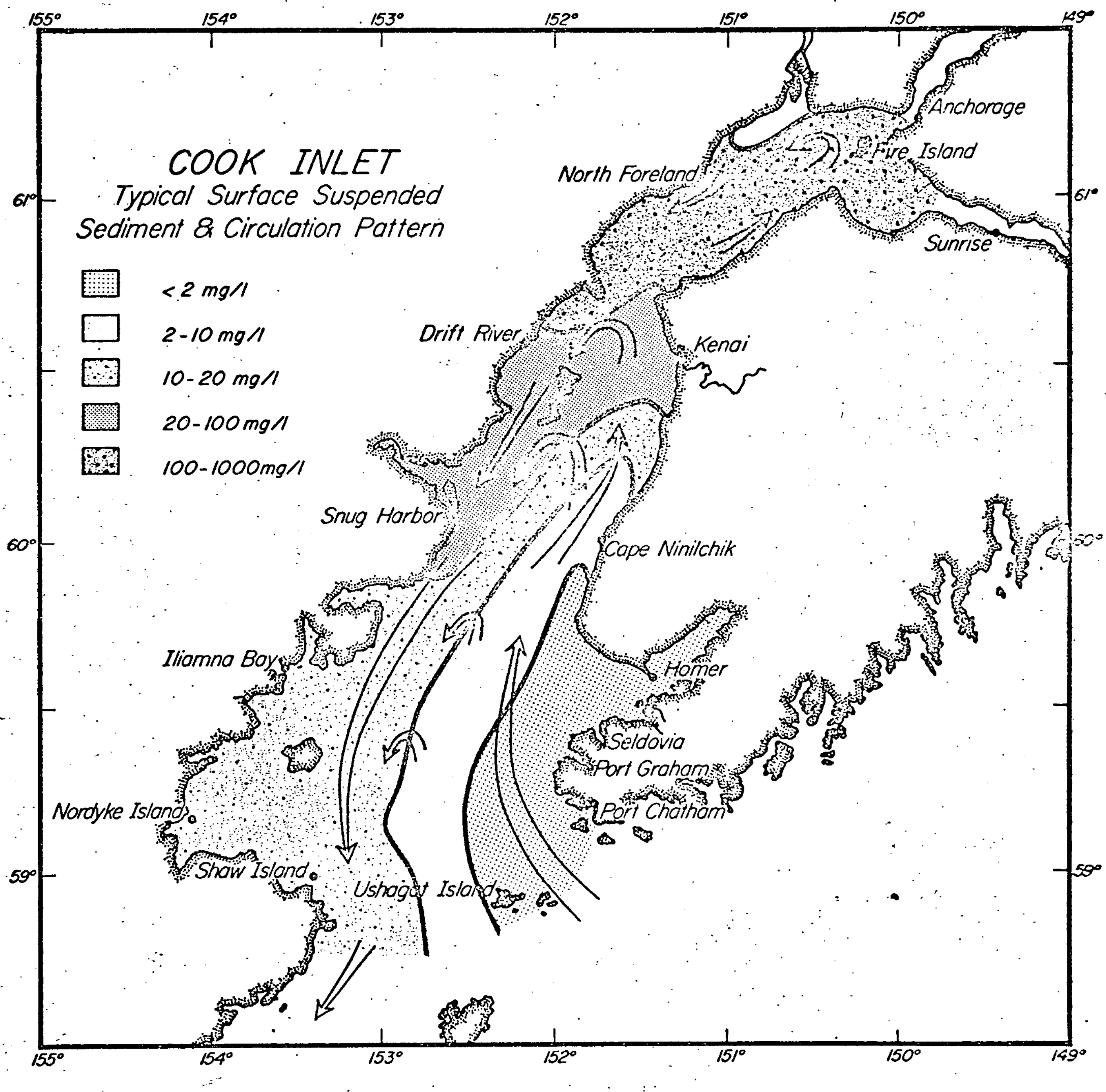

Figure 12. General water circulation and suspended load concentrations in Cook Inlet waters.

variation of as much as 1.0 mg. The material retained on filter paper after filtering one liter of offshore water sample generally weighs between 1 and 2 mg, therefore a better and consistent method for weighing filter paper was developed. The millipore filter papers were washed in distilled water at 50°C for fifteen minutes, rinsed in distilled water and air dried. The filter papers were then put in special chamber attached to a microbalance for 24 hrs. The chamber was continually flushed with air passed through a column containing "Drierite" (anhydrous $CaSO_4$) desiccant. All filter papers were weighed under dry air condition and weights were compared with standard weight as well as standard filter paper weights. The standard deviation of filter paper weight was less than 0.1 mg.

Water samples from various depths at fifty stations in central and eastern Bering Sea was collected and filtered on board "OSHORO MARU," Japanese research vessel. The region of sampling extended between latitude 52°30'-59°00'N and 160°30'-175°00'W. The sampling was conducted between 12 June, and 7 July 1973 in an attempt to obtain ground truth synchronous to overhead satellite passes. Unfortunately cloud cover over the region during sampling did not permit ERTS-1 to obtain imagery for correlation.

On July 6, 1973 another cruise aboard R/V ACONA was initiated at Seward, Alaska. During this cruise sampling was planned to follow ERTS-1 passes between 22-28 July 1973 in the Norton Sound and Bering Strait, and between 9-10 August in Bristol Bay (Fig. 13). Besides water samples and measurements of water parameters at standard hydrographic depths from numerous stations, surface water samples were drawn for filtration at every one half hour (approximately 4.5 n. miles apart) during the entire

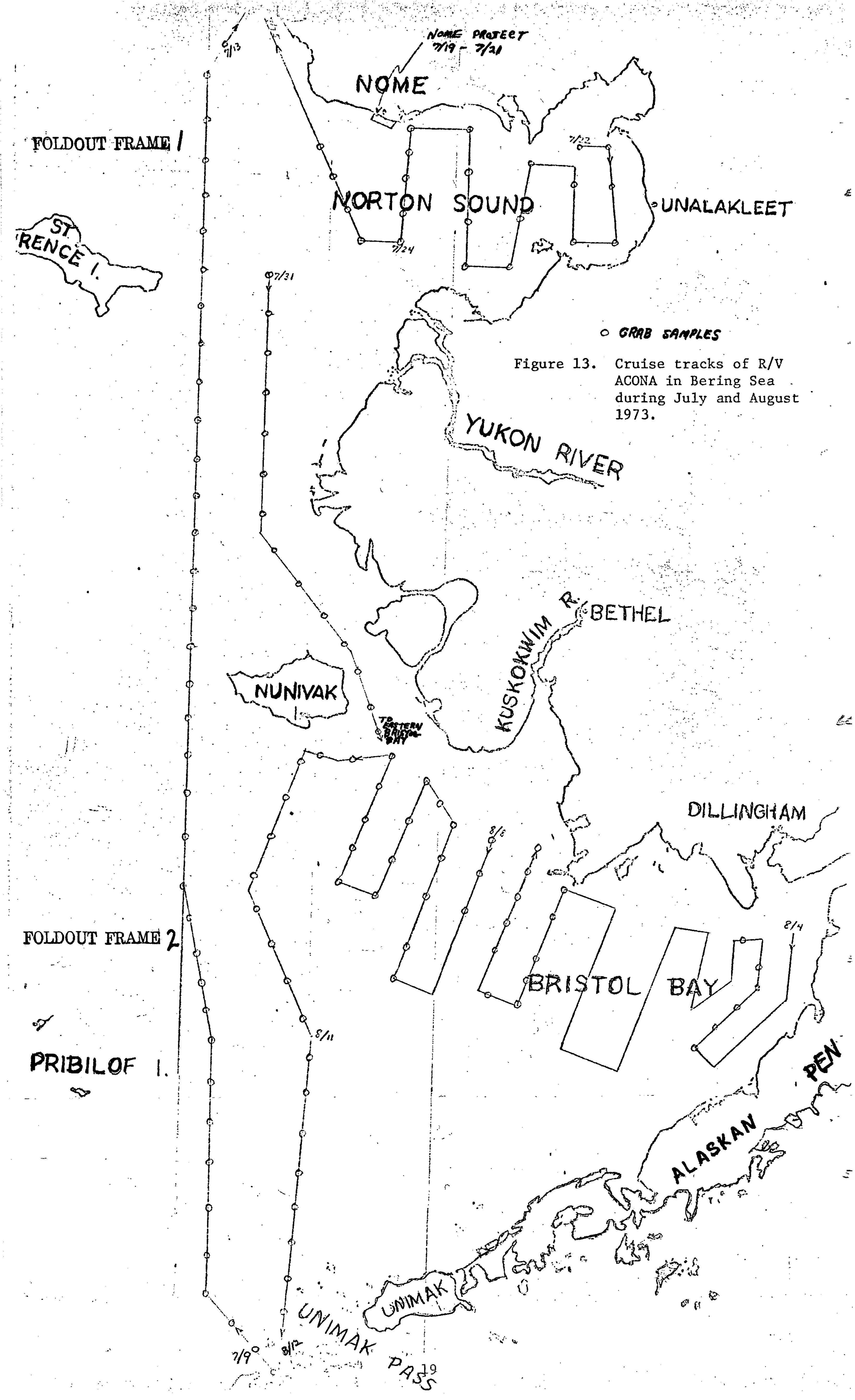

Figure 13. Cruise tracks of R/V ACONA in Bering Sea during July and August 1973.

FOLDOUT FRAME 1

FOLDOUT FRAME 2

cruise. The first leg of the cruise was conducted under cloudy skies and therefore we do not hope to receive any ERTS-1 imagery during this period.

On board observation so far in Bering Sea revealed many interesting areas suited for correlation with ERTS-1 imagery. Although coastal waters contain traceable amounts of sediments in suspension, there are also regions which due to high productivity and biological activity give appearance of turbid waters. The coloration of surface of water in these areas is distinct and slightly greenish. Productivity rates at many stations have been measured and it will be interesting to attempt to correlate these in ERTS-1 imagery. Should this prove fruitful, ERTS-1 imagery may then be used routinely to locate regions of high productivity in the world oceans for fishery resources and regulation.

Various water masses with distinct temperature differences were also observed in northern Bering Sea. It should be challenging to determine the effects of temperature on reflectance spectrum and thus ERTS-1 imagery gray scale. We hope VP-8 density slicing technique should bring out details of subtle variations in sea water reflectance caused by other than suspended load in subarctic waters.

(d) Sea Ice Studies in Chukchi Sea and Bering Sea

The ERTS-1 imagery for ice study has been rewarding. The analyses of few images obtained and described here clearly demonstrate the usefulness of ERTS-1 imagery for routine study of sea ice features in high latitudes. The ERTS-1 image ID. 1010-22135 MSS-5 covers the area along the northwest coast of Alaska showing the prominent landmarks of Ice Cape, Wainwright, and

Point Franklin (Fig. 14). The analysis shows (see attached overlay) the southern edge of seasonal sea ice, which is undergoing both rapid deterioration and northward movement in the northwestern corner of the image. Different characteristics of the sea ice are quite discernible and have been delineated on the attached overlay. Measurements of areal extent of the different ice types were not made; however, the task can be achieved without difficulty. The image shows clearly that most of the snow cover has already melted except on the larger, irregular and rough ice floes. These floes (indicated by the number 5, Fig. 14) appear to be remnants of what was formerly heavy, shore-fast ice. It is doubtful that they are floes of multi-year ice, because of their presence in the ice edge, their rough surface sculpture and several other characteristics. Surface water currents, based on the orientation of ice tongues, appear to parallel the coast in near shore areas and to northerly direction away from the coast.

The ERTS-1 image ID 1010-22133 MSS-6 covers the area northwest of Point Franklin which lies adjacent to the image described earlier. Total area covered by drifting ice is much more extensive and provides excellent examples of seasonal ice in the late stages of disintegration (Fig. 15).

Although large irregular polynya are obvious, there are no leads characteristics of sea ice during winter and spring. The loose and fragmented nature of the ice pack preclude formation of distinct leads, as it is driven by the forces of winds and surface water currents. The almost complete loss of snow cover is especially evident in this image, due to the greater extent of ice cover and therefore the increased opportunity for comparison.

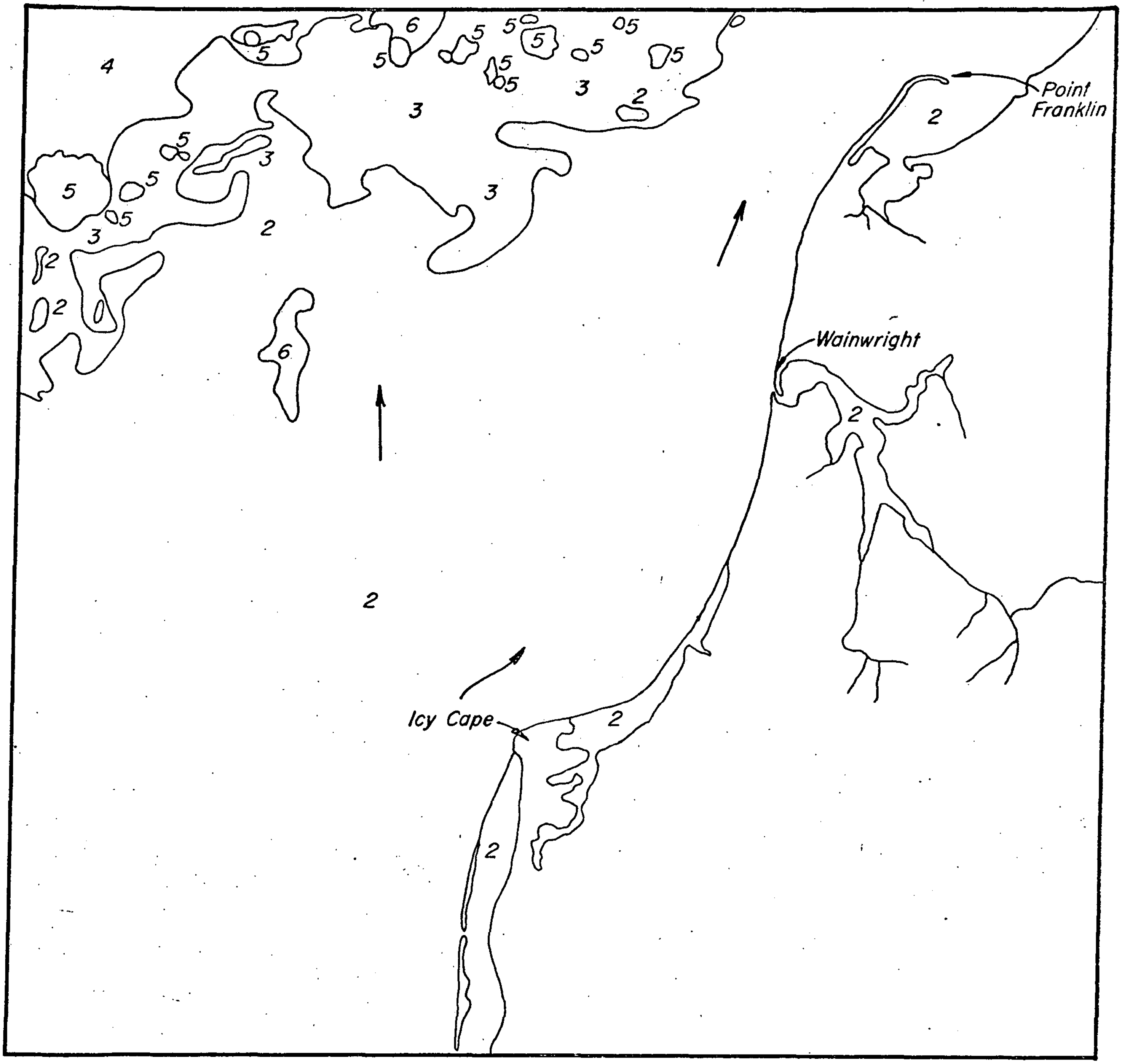

Figure 14. ERTS-1 image ID 1010-22135 MSS-5 with overlay showing characteristics and distributions of various sea ice types in the region of Wainwright, Alaska

1 - Land
2 - Open water (both fresh and salt)
3 - Disintegrating and weathered "ice edge zone"
4 - Disintegrating and weathered "pack ice zone"
5 - Individual and relatively heavy floes
6 - Clouds
7 - Loose and widely scattered floes

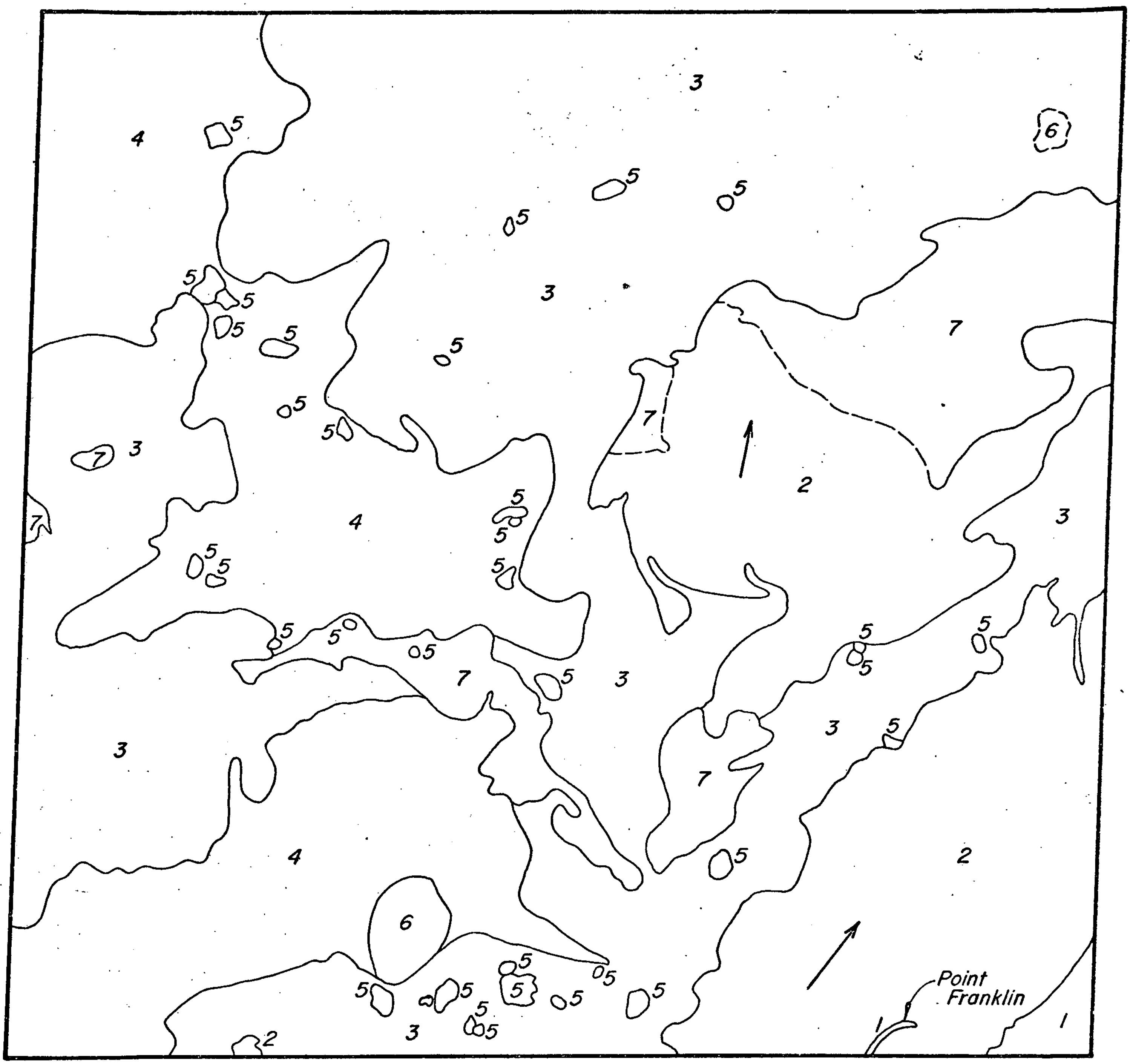

Figure 15. ERTS-1 image ID 1010-22133 MSS-6 with overlay showing characteristics and distribution of various sea ice types in the region of Point Franklin, Alaska

1 - Land
2 - Open water (both fresh and salt)
3 - Disintegrating and weathered "ice edge zone"
4 - Disintegrating and weathered "pack ice zone"
5 - Individual and relatively heavy floes
6 - Clouds
7 - Loose and widely scattered floes

Tonal differences in ice zones are particularly evident as is the actual structure of ice within the zones. This is especially useful in delineating the various zones (see attached overlays). Orientation of ice features again indicate currents parallel to the coast in the near shore areas and more northerly farther off-shore.

ERTS-1 image ID 1087-20595 MSS-5 covers the northern coast of Alaska; Barter Island being the prominent land-head (Fig. 16). The image shows the process of ice formation during early fall, and is an excellent example of the detail and fine resolution which can be obtained from ERTS-1 imagery.

At the time this image was taken, the pack ice was approximately 65 to 70 miles north of Barter Island. Active ice formation was occurring in the open ocean and is evident as thin "grease" ice and slightly thicker but unconsolidated "slush" ice. The pattern of surface currents is particularly evident, paralleling the coast in the near shore and consisting of many eddies and gyres further off-shore. The general direction of currents (and ice movement) is toward the west.

Ice cover in the Bering, Chukchi and Beaufort seas results from two major processes which are evident in this image. These are the formation of new ice, more or less *in situ*, and the movement of previously formed ice into the area.

Interpretation of sea ice will be accomplished on all useable ERTS-1 imagery and will be correlated with ground truth data recently obtained during low level NASA flights in Bering Sea.

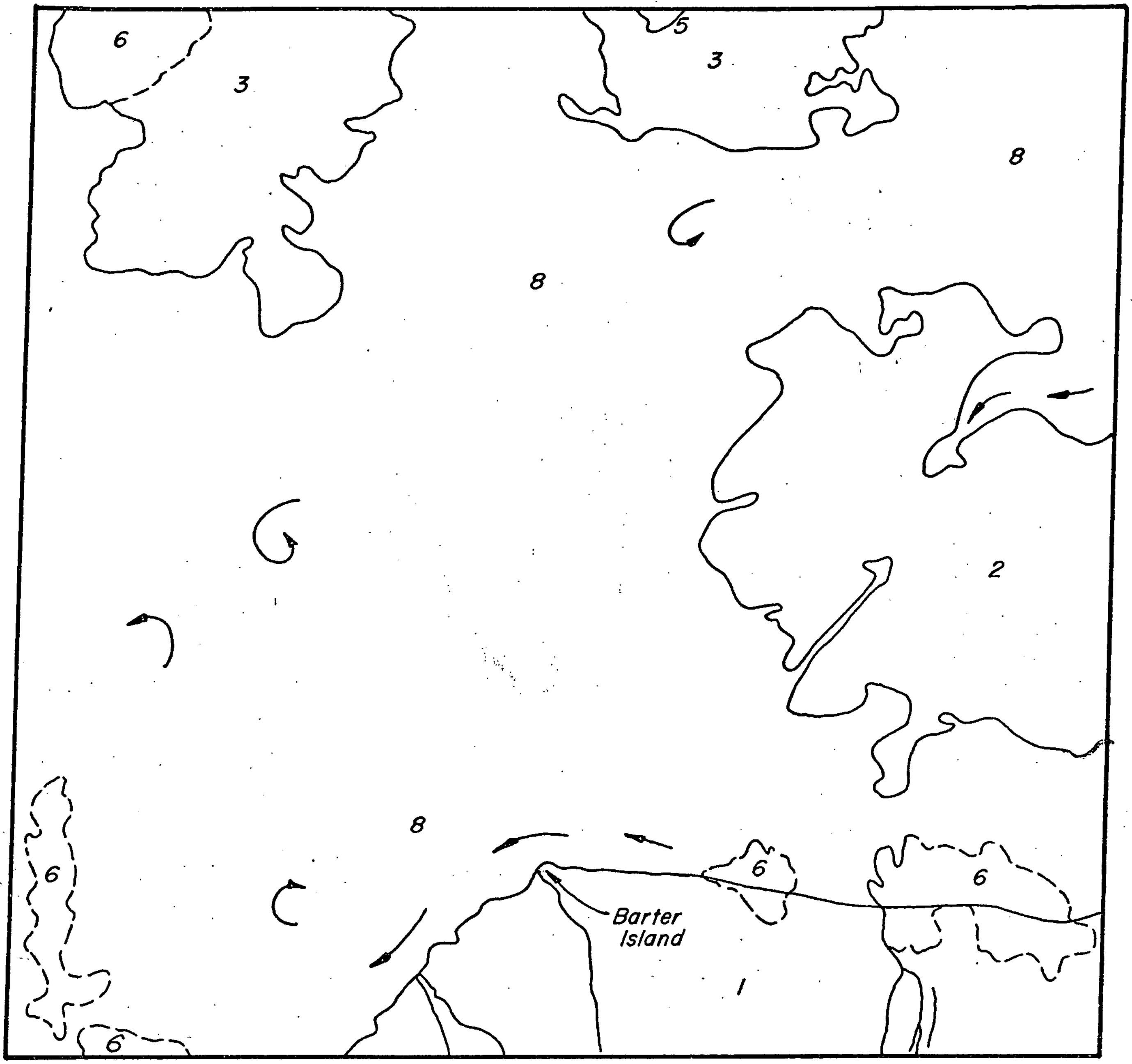

Figure 16. ERTS-1 image ID 1087-20595 MSS-5 with overlay showing characteristics and distributions of various sea ice types in the region of Barter Island, Alaska

1 - Land covered with snow
2 - Open water
3 - Edge zone of the pack ice, also covered with snow
5 - individual and relatively heavy floes
6 - Clouds
8 - Actively forming, unconsolidate "slush" and "grease" ice

ERTS-1 imagery obtained during 6, 7 and 8 March 1973 passes over the regions of eastern Chukchi and Bering Seas was analysed in detail. The individual ice masses on these prints can be easily delineated and thus their movement can be traced during subsequent imagery. Sequence of three images provide the distribution of various ice types and their movements in the Bering Strait during this period (Fig. 17).

The boundaries of land fast ice, distribution of pack ice and major polynya were studied in the vicinity of Bering Strait. Movement of pack ice during 24 hours was determined by plotting the distinctly identificable ice floes on ERTS-1 imagery obtained from two consecutive passes.

Considerably large shallow area along the western Seward Peninsula just north of Bering Strait is covered by land fast ice. This ice hinders the movement of ice formed in eastern Chukchi Sea southward through the Bering Strait. The movement of ice along the Russian coast is relatively faster. Plotting of some of the ice floes indicated movement of ice in excess of 30 km in and south of Bering Strait between 6 and 7 March, 1973. North of Bering Strait the movement of ice approached 18 km. The movement of individual ice floes varied considerably both in southern Chukchi and northern Bering Sea.

The movement of ice observed during March 6 and 7 considerably altered the distribution and extent of polynya. These features when continually plotted should be of considerable aid in navigation for ice breakers. The movement of ice when correlated with distribution of sea mammals should reveal the seasonal migratory habits and routes of these mammals.

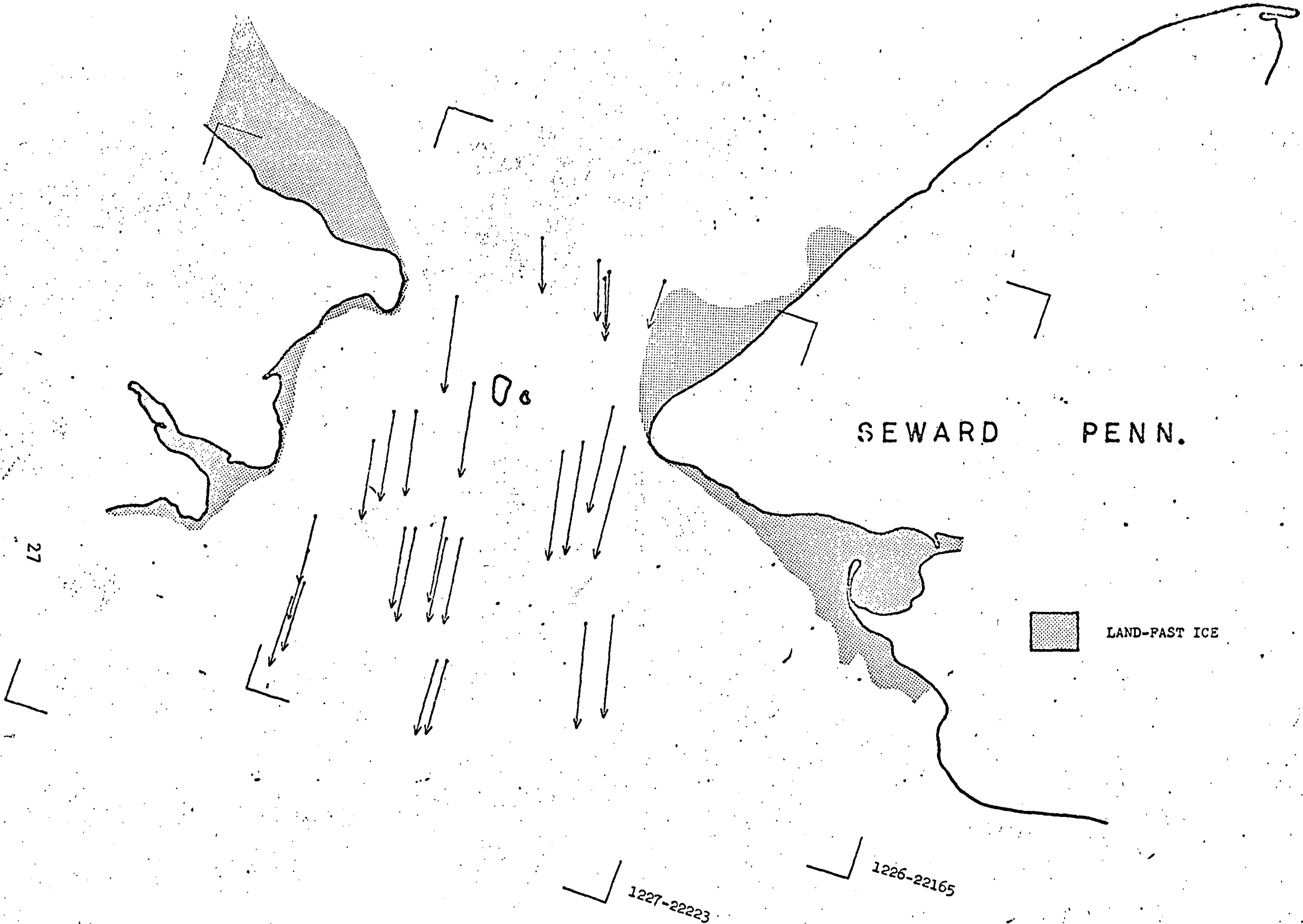

Figure 17. Movements and directions of ice floes in Bering Strait and Bering Sea during 6 and 7 March 1973.

C. Applicability of ERTS-1 data to project objectives

The ERTS-1 imagery is well suited for the study of surface circulation and tracing the pathways of material in suspension. Various water masses in the oceans can also be identified on imagery. Dodged prints of imagery have been extremely useful in tracing turbid waters and thus show clearly mixing and circulation of shelf waters.

Preliminary analysis of Cook Inlet imagery utilizing the VP-8 density slicing equipment show far greater detail of sediment distribution than dodged prints. Thus far, the analyses have shown excellent correlation with known concentrations of the suspended load. Further analyses, it is hoped, will identify regions of high productivity and areas of upwelling.

Utility of ERTS-1 imagery for mapping of various types of sea ice and their movement has been highly successful. Routine plotting of ice movement over a period of several seasons may result in improved navigation and the understanding of dynamics of ice formation and its extention in the Bering Sea.

D. Results

ERTS-1 imagery proved to be well suited for the study of circulation and mixing on shelf waters. It is particularly useful for estuarine studies. In the imagery obtained from Cook Inlet turbid runoff, relatively clear ocean and the mixed waters can be readily distinguished. Suspended load in waters can be related to corresponding radiance values (reflectance spectrum) on MSS bands 4-7. The hydrographic data collected so far correlates to the water circulation and mixing observed in the ERTS-1 imagery of Cook Inlet.

The study of surface water circulation on shelf is far more important than of academic interest. Tracing of turbid waters, particularly orginating from populous coastal communities would essentially permit us to follow in detail the trajectory of pollutants discharged into the sea. Similarly the movement of accidental spills from oil tankers or offshore oil well platforms can be predicted. Migration of the salmon in the coastal waters known to be related to water movements and mixing of turbid runoff but little systematic study has been made. ERTS-1 imagery is a very useful tool to obtain synoptic information over large area and can provide an aid in regulating biological resources, abatement of pollution and coastal management in Alaska.

Routine identification and mapping of sea ice types and their movement over a large area in arctic and subarctic waters has been made possible by ERTS-1 imagery. Open lead and polynya are clearly discernible and their distributions when related to sea mammal population should enhance our understanding of the ecology.

III. NEW TECHNOLOGY

None

IV. PLANS FOR NEXT REPORTING PERIOD

Data and samples obtained from Bering Sea will be processed. In particular the filter papers with sediments will be weighed during August and September 1973.

Useable imagery obtained during last summer has been sorted and large (9"x9") negatives and positives have been requested for density slicing. Suspended load concentrations will be color coded and their distributions will be photographed. The color photographs then will be assembled together to prepare a photomosaic of the Alaskan coast. Photomosaics of dodged prints will be also made to show circulation and mixing of waters. Eventually we hope to cover the entire coast of Alaska to prepare an "Atlas".

Maps for seasonal extension of sea ice in Chukchi Sea and Bering Sea will be prepared and whenever sequential imagery is available the movement of sea-ice floes will be charted.

V. CONCLUSIONS

Extensive and persistent cloud cover has hampered our program. Cook Inlet survey, however, has demonstrated that by repeated sampling areas with stable water parameters can be identified. These areas can serve as ground truth for the analyses of non-synchronous ERTS-1 imagery. Extensive data has been collected in Bering Sea and Gulf of Alaska in an attempt to correlate the water parameters with ERTS-1 imagery to delineate surface water circulation.

ERTS-1 imagery can routinely provide sea-ice distribution and movement. The mapping of open leads and polynya during winter month should be a valuable navigational aid in Arctic and subarctic waters.

VI. RECOMMENDATIONS

None

VII. PUBLICATIONS

1) Surface Currents, Suspended Sediments and Ice Cover in the Bering Sea and their Possible Influence on the Regional Climate. 24th Alaskan Science Conference. Aug. 15-17, 1973.
2) ERTS Studies of Alaskan Coastal Circulation. American Society of Photogrammetry, Symp. on Remote Sensing in Oceanography, Orlando, Florida (Text in press).
3) Satellite Observations of High Latitude Estuarine Circulation, Port and Ocean Engineering Under Arctic Conditions, University of Iceland. (Abstract accepted; Text in preparation).

VIII. REFERENCES

Sharma, G. D., A. S. Naidu, and D. W. Hood, 1972, Bristol Bay: A contemporary graded shelf. Am. Assoc. Petroleum Geologists Bull. V. 56 (10), pp. 2000-2012.

ERTS IMAGE DESCRIPTOR FORM

(See Instructions on Back)

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ID

DATE July 31, 1973

PRINCIPAL INVESTIGATOR G. D. Sharma

GSFC UN683

ORGANIZATION University of Alaska

PRODUCT ID (INCLUDE BAND AND PRODUCT)	FREQUENTLY USED DESCRIPTORS*			DESCRIPTORS
	Ocean	River	Plume	Coast
ID 1319-20520 MSS-7	X	X	X	X
ID 1319-20522 MSS-5	X	X	X	X
ID 1319-20522 MSS-6	X	X	X	X
ID 1319-20522 MSS-7	X	X	X	X
I				
ID 1319-20525 MSS-4	X	X	X	X
ID 1319-20525 MSS-5	X	X	X	X
ID 1319-20525 MSS-6	X	X	X	X
ID 1319-20525 MSS-7	X	X	X	X
ID 1320-20581 MSS-4	X	X	X	X
ID 1320-20581 MSS-5	X	X	X	X
ID 1320-20581 MSS-6	X	X	X	X
ID 1320-20581 MSS-7	X	X	X	X
ID 1320-20583 MSS-4	X	X	X	X
ID 1320-20583 MSS-5	X	X	X	X
ID 1320-20583 MSS-6	X	X	X	X
ID 1320-20583 MSS-7	X	X	X	X

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SIXTH BIMONTHLY PROGRESS REPORT

University of Alaska
ERTS Project No. 110-8
July 31, 1973

PRINCIPAL INVESTIGATORS: G. D. Sharma, F. F. Wright and J. J. Burns

TITLE OF INVESTIGATION: Sea Ice and Surface Water Circulation, Alaskan Continental Shelf.

DISCIPLINE: Marine Geology and Ecology

SUMMARY OF SIGNIFICANT RESULTS:

Over 1,500 water samples from surface and from standard hydrographic depths were collected during June and July 1973 from Bering Sea and Gulf of Alaska. The measurement of temperature, salinity and productivity indicated that various distinct water masses cover the Bering Sea shelf. The suspended load in surface waters will be correlated with the ERTS-1 imagery as it becomes available to delineate the surface water circulation.

The movement of ice floes in the Bering Strait and Bering Sea indicated that movement of ice varies considerably and may depend on wind stress as well as ocean currents.